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Predicting Contaminant Removal Effectiveness of Three Air Distribution Systems by CFD Modeling

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ABSTRACT

This study compares the contaminant removal effectiveness (CRE) of three air distribution systems for a bar/restaurant setting by use of computational fluid dynamics (CFD) modeling. The air supply distribution and exhaust arrangement were modeled for a mixed air system, a directional air flow system (where air moves in a unidirectional flow pattern across the space, from the high-pressure supply area to the low-pressure exhaust area), and a displacement ventilation system (where supply air is delivered at low velocity close to the floor, allowing thermal plumes to be created). The CRE of each space was determined for both particulate and carbon monoxide dispersions under two different ventilation rates. A commercial CFD software package was used to model a hypothetical restaurant with bar in a steady-state condition with the inclusion of objects, such as a bar and multiple tables, heat sources such as people standing and seated, pollutant sources, multiple four-way supply air diffusers, and an exhaust air grille. The hospitality spaces' smoking and nonsmoking zones had no physical separation. The results demonstrated that directional airflow systems reduce nonsmokers' exposure to contaminants better than mixed air systems, and displacement ventilation systems reduce nonsmokers' exposure better than both directional airflow and mixed air systems.

INTRODUCTION

The purpose of any ventilation system is to provide a sufficient amount of outdoor air to remove contaminants and to maintain the interior environment at a comfortable temperature and relative humidity. The effectiveness of a ventilation system to perform these functions can be quantified in a number of ways e.g., air change efficiency of a system looks at air flow patterns only (Chow and Fung 1996; Nielsen 1993; Roos 1999), whereas contaminant removal effectiveness (CRE) quantifies the dilution and removal of a contaminant by a system. CRE is defined as the ratio between the steady-state concentration of the contaminant at the exhaust and the room or zone average value (Liddament 1993; Yaglou and Witheridge 1937).

The evaluation of CRE of three air systems was carried out using computational fluid dynamics (CFD) modeling. CFD modeling software has only recently become commercially available to heating, ventilating, and air-conditioning (HVAC) engineers in a package simple enough to learn and apply in a fairly short time. One virtue of CFD modeling is that it allows specific entry of details of the room that have relevance to the airflow. This feature is one that sets it apart from simple mass balance type models (Klepeis et al. 1996; Ott 1999) in which a room is largely described by its volume. CFD models have been used recently to study indoor air quality (IAQ) problems, pollutant dispersions, and performance of HVAC systems (Chow and Fung 1996; Emmerich 1997; Gadgil et al. 1999). Indoor environments studied using CFD modeling included offices (Reynolds and Hedge 1999), research laboratories (Memarzadeh 1999), an operating theater (Tinker and Roberts 1999), and an industrial workshop (Peng and Davidson 1998). Previous studies involving the evaluation or comparison of different air distribution systems have been published (Jiang et al. 1992; Holmberg et al. 1999; Kolokotroni et al. 1995; Yeoh and Li 1998). Ventilation plays an important role for reducing environmental tobacco smoke (ETS) in the design for smoking areas (ASHRAE 1981, 1989; Bohanon et al. 1998). The effect of ventilation on reducing ETS has been quantified in both laboratory studies (Cain et al.

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